Impact to Cooling Airflow from Truck Platooning

Preprint

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National Renewable Energy Laboratory

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Impact to Cooling Airflow from Truck Platooning

Abstract

We investigate tradeoffs between the airflow strategies related to engine cooling and the aerodynamic-enabled fuel savings created by platooning. By analyzing air temperatures, engine temperatures and cooling air flow at different platoon distances, we show the thermal impact to the engine from truck platooning. Previously, we collected wind and thermal data for numerous heavy-duty truck platoon configurations (gaps ranging from 4 to 87 meters) and reported the significant fuel savings enabled by these configurations. The fuel consumption for all trucks in the platoon were measured using the SAE J1321 gravimetric procedure as well as calibrated J1939 instantaneous fuel rate while travelling at 65 mph and loaded to a gross weight of 65,000 lb. Using thermocouples mounted 1 m ahead of each truck, anemometers at the grill and a grid of under-hood thermocouples as well as J1939 reported engine temperatures, we analyze the impact to critical operating temperatures from different platoon configurations. Results show significant changes in the engine and under-hood air temperatures that correlate with vehicle gap distance and platoon position.

Keywords: Engine cooling, cooling air flow, adaptive cruise control (ACC), cooperative ACC (CACC), heavy-duty truck platooning, heavy-duty truck partial automation, heavy-duty truck fuel economy, connected and automated vehicle

Introduction

Currently, connected and automated vehicle technologies are of great interest and the subject of much research in the automotive and trucking industries. For heavy-duty commercial vehicles, the biggest advancement in near-term connected and automated vehicle-related technology is platooning. The essence of platooning is that several heavy-duty trucks are operated in close proximity with close coordination through a Dedicated Short-Range Communication vehicle-to-vehicle system, radar, and/or video camera with the goal of reduced fuel consumption and improved safety.

Previous studies [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15] have investigated the fuel savings benefit and aerodynamic mechanisms that lead to these beneficial effects. McAuliffe et al. [12] conclude that there are two dominant aerodynamic phenomena that lead to reduced drag and fuel consumption. Figure 1 from McAuliffe et al. [15] illustrates these drag-reduction mechanisms. This current study considers the impact those phenomena have on the air temperatures and air speeds encountered by the following trucks in the platoon. Specifically, how does operating in a region of lower airspeed, relative to the following vehicle and likely lower stagnation pressure over the front surfaces of the trailing vehicle, impact engine cooling performance. McAuliffe et al. [12], found the magnitude of these two effects are influenced primarily by the separation distance between the trucks and therefore it would be expected that cooling performance would similarly be influenced by following distance.

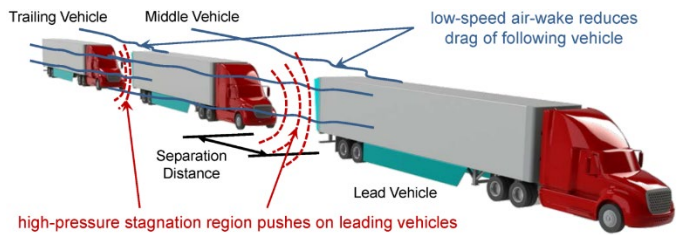

Figure 1. Simplified representation of the aerodynamic phenomena influencing heavy vehicles in close proximity (McAuliffe et al. [15])

Previous Test Description

In 2017, the National Renewable Energy Laboratory (NREL), in cooperation with Lawrence Berkeley National Laboratory, Transport Canada, and National Resource Council Canada, launched a truck platooning track test campaign. The main purpose of this campaign was to extend the knowledge of platooning savings and confirm significant questions around truck platooning's real-world savings potentials. As part of that campaign, the test vehicles had significant additional instrumentation installed that was not evaluated in the original study [15]. The original study did have major findings regarding fuel consumption in truck platoons:

- Significant fuel savings for the middle and trailing vehicles of 6% and 8%, respectively, were measured at the largest separation distance of 87 m.
- Total fuel savings for the three-vehicle platoon was measured at 13% at the shortest separation distance of 4 m, with 4.5% savings measured at 87 m.
- Trends in data compare well with other fuel-economy data sets for similar vehicle types, speeds, and weights.

More details about the tests and results of the past work can be found in [15].

Objectives of the Current Work

From the results of truck platooning track tests, it is obvious that the fuel savings from truck platooning are higher at shorter separation distances while still significant at very long distances. But an optimal fuel saving platooning configuration for heavy-duty trucks could have unintended consequences regarding the design of the vehicle's thermal management systems and even relatively longer distances may have an impact. Muratori et al [16] identified that 66% of class 8 tractor miles are at platoonable speeds and that for early adopter fleets 77% of miles are at platoonable speeds. Early adopter fleets may be able to schedule their trucks to always have a platooning partner available and as such truck manufacturers may need to consider the thermal impacts to engine efficiency and component durability of elevated temperatures from close platooning for such a high fraction of miles traveled. This work intends to identify what those thermal impacts may be while understanding they are not likely to have immediate impacts to the measured fuel savings from platooning.

The original tests included various scenarios, such as three trucks platooning from 4 m to 87 m separation distances, two trucks platooning from 6 m to 58 m separation distances, contrast platooning to long combination vehicles, mismatched trailers, speed variation, and travelling with other traffic. For the current work, only the first test scenarios, namely various distances among three trucks platooning, are addressed to investigate the thermal impacts throughout the previously tested platooning distances. The objective of this study is to provide decision makers in the truck and engine manufacturing industry with detailed information to understand the impacts of customers with a high percentage of miles driven in close platoon formation.

Test Setup and Procedure

In this section, pertinent specifics regarding instrumentation relevant to the present work are duplicated from the original work [15] or detailed more extensively than the original work. The related test track and vehicle descriptions, test procedures, and test details are not duplicated as they were discussed in detail in the previous work [15]. The original test adhered to J1321 [17] procedures and other measures to ensure repeatable test conditions such as:

- Specified vehicle warm up procedures and maximum transition time between test runs to ensure all vehicle systems were at highway operating temperatures
- Air conditioning always on with consistent fan settings
- Engine fan engagement and DPF regeneration events would disqualify test runs

Data Collection System

In addition to the standard J1321 gravimetric testing procedure, a data collection system was installed on all three test trucks that collected J1939 controller area network (CAN) bus signals as well as the additional onboard instrumentation related to temperatures and airflow. In addition, an onsite weather station recorded ambient conditions during the tests.

CAN Bus Data Collection

The CAN bus system is the “nervous system” used in vehicles for communications among the engine control unit, sensors, and actuators. The data collection system recorded information related to engine operation, such as engine speed, engine torque, and temperatures at 1 Hz. Specifically, the following engine control unit parameters were recorded and used to conduct the present analysis of the engine thermal management system:

- Engine intake air temperature
- Engine intake manifold temperature
- Engine coolant temperature
- Engine oil temperature.

Engine exhaust gas temperatures were also analyzed but are not presented here as they show no correlation to vehicle separation distance or platoon position and are impacted by other variables outside the scope of this work.

Temperature measurement system

To investigate the effects of the heavy-duty truck platooning on the cooling air flow, as well as the thermal burden on the engines, several temperature measurement systems were in use during the test to provide comprehensive information related to both the ambient environment as well as temperatures around and within vehicles.

Boom-Mounted Temperature

During the test campaign, each vehicle was equipped with a boom extending 1 m ahead of each vehicle and 2 m off the ground (as shown in Figure 2). The boom was used to mount a thermocouple used in the current analysis as well as a COBRA probe for airspeed measurement that is not used here. The thermocouple provides temperature information about the air steam just ahead of each vehicle.

Figure 2. Photograph of boom for mounting boom location probe and thermocouple ahead of vehicle hood

Since all three trucks are instrumented in the same manner, the temperature differences among these three trucks can provide thermal gradients within the three-truck platoon due to the heat of the previous vehicle(s) engine/exhaust and/or air friction from their passing and how the gradient changes based on different separation distances. Figure 3 shows range of temperature measurements at the boom location for each truck during each reference test. The differences may be caused by the accuracy of the thermocouple mounted on the boom location or may be caused by the various environmental conditions that three trucks encountered during the test. However, the absolute variances of the three sensors in each test are within ± 0.5 °C.

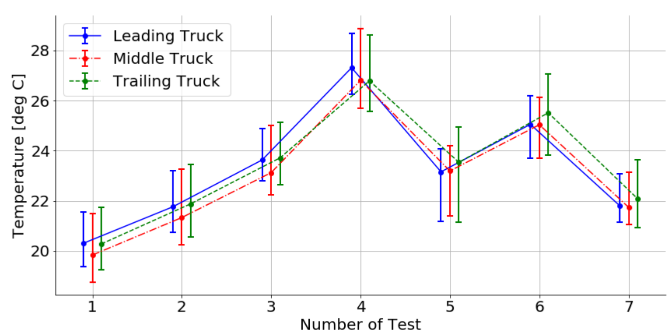

Figure 3. Boom-location temperature measurement along the seven reference tests

Under Hood Temperature

Six thermocouples were installed in each truck in a grid attached under the hood of each truck with a 1-inch air gap to the hood surface. These thermocouples measure the spatial distribution of the temperatures under the hood during the tests. The corresponding reference test results are shown in Figure 4 for the under-hood temperature. It worth noting that the under-hood temperature is derived by averaging the six under-hood thermocouples. While the measurement accuracy may be diminished due to this fact, the absolute variances of the under-hood temperature measurement for the three trucks in each test are within ± 1.8 °C.

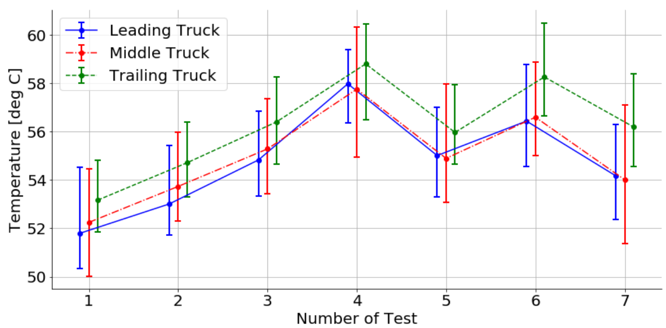

Figure 4. Under hood temperature measurement along the seven reference tests

On-site weather station

In addition, the ambient temperature, humidity, barometric pressure, and wind speed and direction were also measured at the test site through an on-site weather station, as shown in Figure 5. To ensure the accuracy of the measurement through this weather station, all the data were verified using climate data from the Mirabel Weather Station, located 12 km from the test site.

Figure 5. Photograph of on-site weather station

Figure 6 shows the ambient temperature distribution for the various reference tests of the three-truck platooning test. To include all the information related to the ambient temperatures, the data in Figure 6 represent the mean value of the time-based ambient temperatures and also show the 25% and 75% quartiles of the related data by the bars above and below the mean value point.

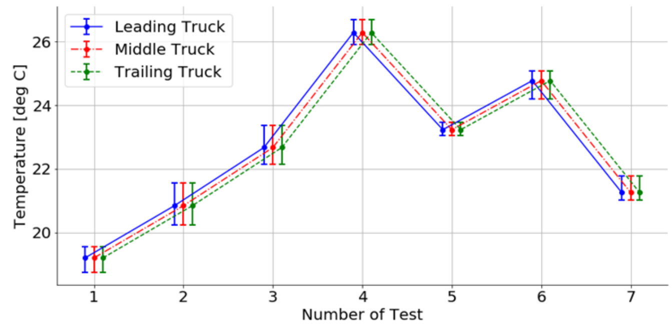

Figure 6. Ambient temperature distributions along the seven reference tests

From Figure 6, the averaged ambient temperatures for each reference test are in the range of 20°C to 27°C because the corresponding tests may be conducted on different days. All three trucks share the same ambient data source.

Grill Air Flow

An anemometer was also mounted flush on the center of grill of each truck in the test, as can be seen in Figure 7. This device measures the air flow into the cooling package. Due to its location, the measurement shows the ram air the cooling package has to work with.

Figure 7. Photograph of anemometer mounted on the center of grill

Results and Discussion

The distributions of ambient temperatures, boom location temperatures, and under-hood temperatures are investigated at the various separation distances of the three trucks platooning test. Both the mean value, 25% to 75 % quartiles of the data as well as the related violin plots, are shown in the following sections to provide more comprehensive interpretation of the relationship between the truck platooning separation distance and the related various spatial temperature distributions.

Beside the temperatures outside the engine, the engine CAN bus system also provides specific temperature data within the engine. As a result, the distribution of the intake air temperature, intake manifold temperature, engine coolant temperature, and engine oil temperature for the same test scenarios are also presented. These data reflect the thermal control of the engine in the platoon environment.

It worth noting that there are nine test scenarios for the three truck platooning tests, with separation distances of 4 m, 6 m, 9 m, 12 m, 18 m, 35 m, 44 m, 58 m, and 87 m. Unfortunately, due to some technical issues, the data for the ambient temperature, boom location temperature, and under-hood temperature for the tail truck at the 18-m separation distance were not recorded. However, in spite of the data missing at this specific distance, the trends of the temperature distributions are still clear.

Boom Location Temperature

The distributions of air temperature measured by the boom location thermocouples from the three trucks are shown in Figure 8. This temperature measurement largely mirrors ambient measurements at the longer following distances, but at distances less than 20 m, the following trucks measure elevated temperatures for the incoming air. Due to the location of the boom thermocouple, the trucks ahead of it can influence the air temperatures, and as such, the position in the platoon matters at gap distances of 18 m and less.

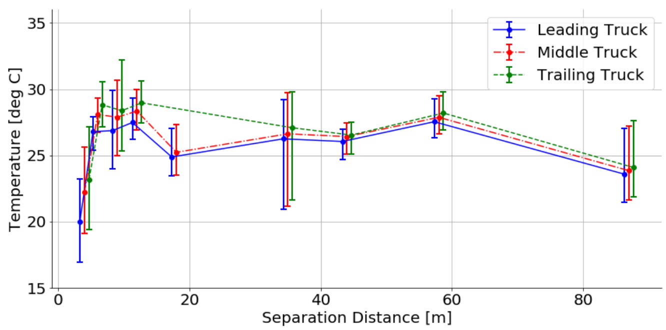

Figure 8. Boom location temperature distributions at various separation distances in the three-truck platooning test

An investigation of the boom location temperatures from different trucks shows that the trailing truck always has a little higher boom location temperature at all the separation distances. The middle truck had a lower boom location temperature compared to the trailing truck, and the boom location temperature from the leading truck is the lowest. This trend shows that the trailing truck must use nominally higher-temperature incoming air for cooling.

In addition, the differences of the boom location temperatures among the three trucks are also increased when the separation distances are reduced. For example, at an 87-m distance, the boom location temperature difference between the leading and trailing trucks is within 1°C, while at the 4-m case, the corresponding temperature difference is about 3°C.

Under-hood Temperature

Six thermocouples mounted at different locations under the hood measure the spatial distribution of the air temperatures under hood. Since the operating engine is the major heat resource in this volume, the under-hood air temperature is mainly affected by the heat from the engine.

In this analysis, the temperatures measured by the six thermocouples are averaged first. Then, the averaged temperature is used as the under-hood temperature. The average temperature distributions during all platooning tests are represented in Figure 9. The under-hood temperatures among the three trucks are quite similar when the separation distance is larger than 35 m. Specifically, the variation range of the corresponding under-hood temperature is less than 4°C. However, when the separation distance becomes less than 18 m, the under-hood temperatures of the middle and trailing trucks rise significantly, while the under-hood temperature of the leading truck is still comparable to the longer separation distance case. As can be seen, the under-hood temperatures from the middle and trailing trucks have risen to almost 75°C at a 4-m separation distance, whereas the counterpart temperature in the leading truck is only 52°C, which is even lower than the longer separation distance case due to lower ambient temperatures for those tests.

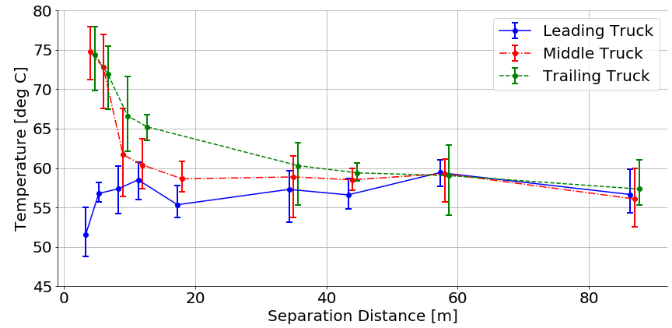

Figure 9. Under-hood temperature distributions at various separation distances in the three trucks platooning test

The lower under-hood temperature of the leading truck at shorter separation distances is caused mainly by relatively lower ambient temperature. To get rid of this impact, the temperature difference between the under-hood temperature and the boom location temperature for the three trucks at various separation distances are shown in Figure 10. The temperature rise from the boom location temperature to the under-hood thermocouple grid is almost identical for the leading truck from 4 m to 87 m, which is within 30° to 34°C. In other words, the engine bay of the leading truck is operated in almost a constant thermal condition during all the platooning tests. However, the corresponding temperature rise for the middle and trailing trucks are from 32° to over 50°C as the separation distance is reduced from 87 m to 4 m. As a result, the engines in the middle and trailing trucks operate in a more elevated thermal condition while the trucks platoon at a short distance.

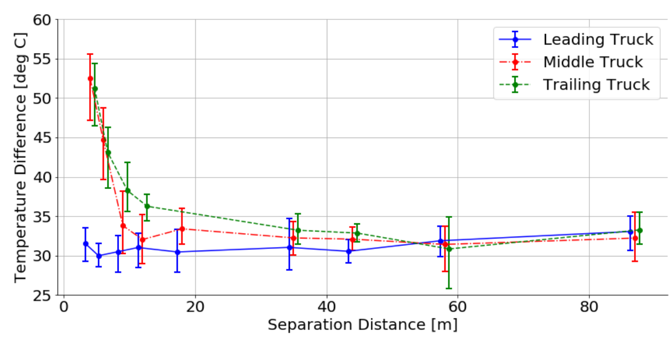

Figure 10. Difference between boom location temperature and under-hood temperature distributions for various separation distances in the three-truck platooning test

Intake Air Temperature

In addition to the temperature measurement outside the engine, the CAN bus system within each truck provides more direct information related to the thermal condition while the engine operating. In this section, the intake air temperatures captured by the engine CAN bus system are analyzed, and the corresponding results are shown in Figure 11.

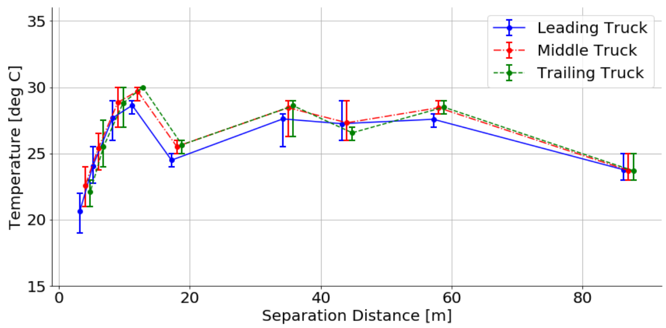

Figure 11. Intake temperature distributions at various separation distances in the three-truck platooning test

Comparing Figure 11, showing the distributions of intake air temperature, to Figure 8, showing the distributions of boom location temperatures, these two distributions have similar trends for various separation distances, while the intake air temperatures are a little bit higher than the corresponding boom location temperatures.

In addition, unlike the boom location temperature distribution, the trailing truck does not always have a higher intake air temperature when the separation distance is longer than 40 m. However, the intake air temperature variation range in those cases is less than 1°C. Furthermore, when the separation distance is less than 20 m and the intake air temperature variations among three trucks are larger, the leading truck always has the lowest intake air temperature, which agrees with the boom location temperature distribution as well.

Intake Manifold Temperature

The second parameter from the engine CAN bus system investigated is the intake manifold temperature. The intake manifold temperature sensor is measuring the same air flow as the intake air temperature sensor, but after the turbo charger has heated and compressed the air and the charge air cooler has cooled it back down. If the intake manifold has a higher temperature, it is reasonable to suspect the efficacy of the charge air cooler is limited, and thus the thermal burden of the engine is increased, and the combustion control system may have to make adjustments.

Figure 12 shows the corresponding results of the intake manifold temperature distribution within the three trucks at different platoon distances. When the following distance is less than 20 m, the intake manifold temperatures are much higher in the middle and trailing trucks compared to the leading truck. Nonetheless, the intake manifold temperatures among the three trucks are comparable to each other, within the range of 2°C, when the distances are longer than 40 m.

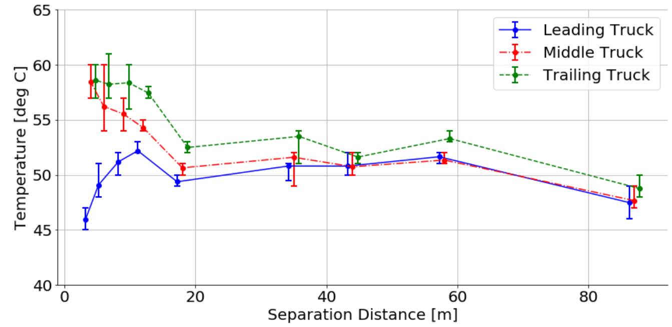

Figure 12. Intake manifold temperature distributions along various separation distances in the three-truck platooning test

Similar to the under-hood temperature, the temperature rise from the intake air to the intake manifold is also derived. The related distributions are shown in Figure 13. As in the previous case, the leading truck almost has a constant temperature difference between these two sensors, which is around 22.5° to 25°C. However, the temperature rises in the middle and trailing trucks are significant when the separation distance is reduced. They are comparable to temperatures in the leading truck at longer distances, and quickly increase from 25°C to 35°C when the distance is reduced from 20 m to 4 m. This observation shows that when the platoon distance is reduced, the charge air cooler has a limited efficacy.

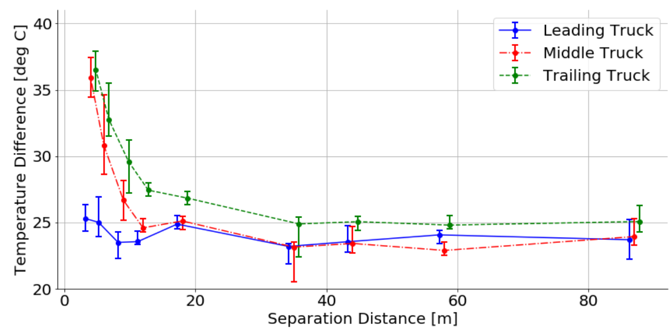

Figure 13. Difference between intake and intake manifold temperature distributions along various separation distances in the three-truck platooning test

Engine Coolant Temperature

The engine coolant is the primary heat rejection system used to ensure the engine operates in an appropriate temperature window. As such, the temperature of the engine coolant is also an accurate indicator to reflect the thermal condition of the operating engine. The engine coolant information for the three trucks has been extracted from the CAN bus system. The corresponding distributions are shown in Figure 14. The coolant temperature is almost constant (around 81°C) for the leading truck regardless of the platoon distances. The middle and trailing trucks have similar coolant temperatures beyond an 18-m separation distance. At shorter distances, the engines' coolant temperatures are elevated - over 92°C at the 4-m case, almost 11°C higher than the engine of the leading truck. It worth noting that the coolant temperature of the trailing truck is always the highest during a specific test.

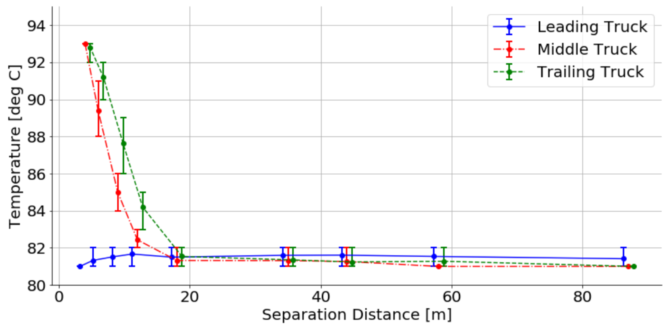

Figure 14. Engine coolant temperature distributions for various separation distances in the three-truck platooning test

Engine Oil Temperature

Finally, the engine oil temperature is also investigated in this study. The engine oil is used to lubricate the mechanical components and minimize the friction losses from the engine. If the temperature is too high, the oil may be degraded, risking excessive wear, possible component damage, and decreased the fuel economy of the truck by increasing the frictional losses. The engine oil temperature distributions are depicted in Figure 15. The averaged oil temperatures are almost identical (within 115° to 117°C) among these three trucks at various distances. The maximum variation at a specific distance is less than 1°C (in the 4-m case), indicating that platooning does not impact oil temperature.

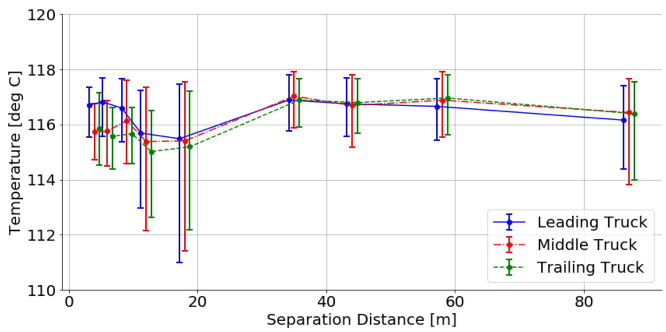

Figure 15. Engine oil temperature distributions for various separation distances in the three-truck platooning test

Grill Air Flow

The anemometer measures the air flow rate going through the front grill. The related results are shown in Figure 16. The air flow rates going through the leading truck are almost identical for different separation distance in the platooning tests. However, the middle truck and trailing truck have the limited air flow rate when the separation distance is reduced to less than 20 meters, which is consistent with the fact that the most of the previously discussed under-hood and CAN bus reported temperatures of these two trucks increased significantly with the reduced separation distance.

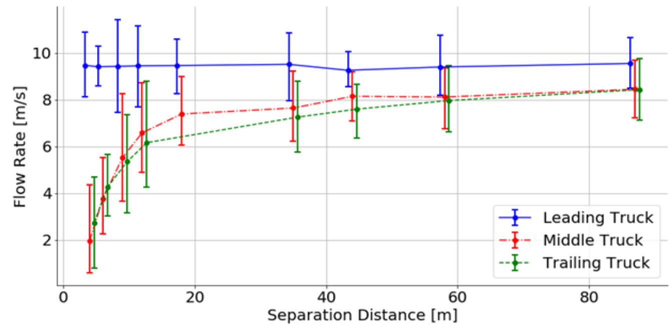

Figure 16. Air flow rate measured by anemometer at grill surface

Detailed Temperature Distribution Outside of Engine

In addition to the averaged values and 25% and 75% quartiles for temperature data shown in Figure 6 to Figure 15, the detailed distributions of the related measurements are also presented in this and the following section via the violin plots. In this section, the ambient temperature, the boom location temperature, and the under-hood temperature are presented, which describe the thermal conditions outside the engine.

A violin plot is a method of plotting numerical data. It is similar to a box plot, except that it also shows the probability density of the data at different values, usually smoothed by a kernel density estimator. As a result, the violin plots, which not only show the mean/median and interquartile ranges of the data but also describe the full distribution of the data, are more informative than plain box plots.

Figure 17 shows the violin plots for ambient temperature (blue), boom location temperature (brown) and under-hood temperature (green) at various platoon separation distances ranging from 4 m to 87 m. For each violin plot, the thick bar in the center represents the interquartile range, and the thin black line extended from that point represents the upper (maximum) and the lower (minimum) adjacent values in the data. In addition, the white dot in the middle of the thick bar is the median value. Finally, the shape of the plots for each data array shows the related density distribution.

All the violin plots are shown at the same scale to provide a clear comparison among the three temperature distributions for the separation distances. At each distance, the boom location temperature is always slightly higher than the ambient temperature. This difference is increased when the separation distance is reduced. The under-hood temperatures are almost identical for the three trucks when their separation distance is more than 20 m. At distances less than 12 m, the under-hood temperatures of the middle and trailing trucks are much higher than the leading truck's. Because each separation distance scenario includes several test runs, which can be conducted at different times, some violin plots may show three separate distributions with the one shape, like the results shown in the 87 m, 35 m, and 9 m scenarios.

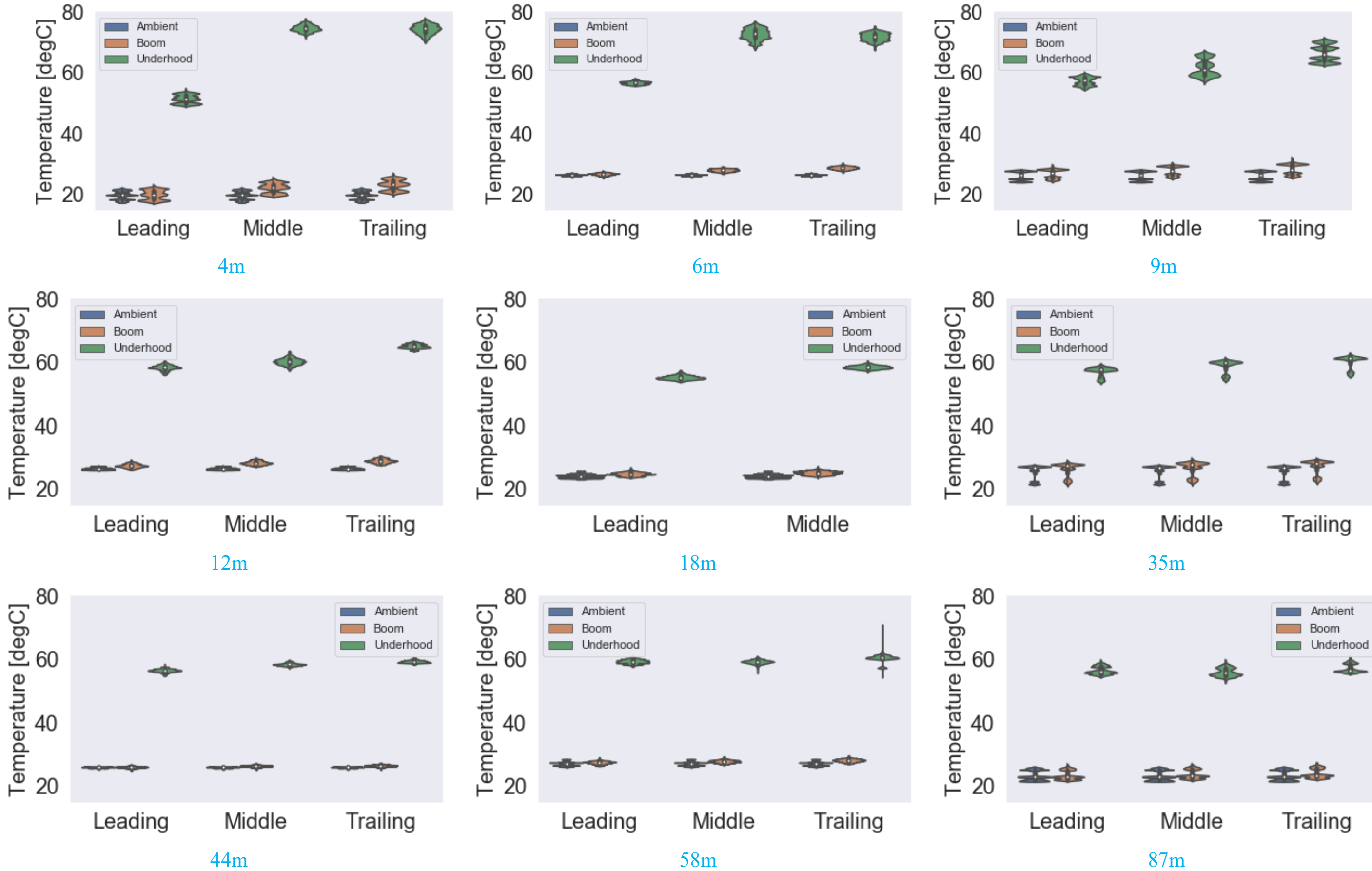

Figure 17. Violin plots of outside engine temperature distributions for various separation distances in the three-truck platooning test

Detailed Temperature Distribution inside Engine

The detailed distributions of intake air, intake manifold, engine coolant, and engine oil temperatures are also investigated in the study, and are shown in Figure 18 in the violin plots (blue for intake air temperature, brown for intake manifold temperature, green for coolant temperature and red for engine oil temperature). Similar to Figure 14, all the platooning distances are considered, from 4 m to 87 m.

As can be seen, the intake air temperature distributions are almost identical for all three trucks at different distances. The intake air temperatures are mainly affected by the ambient temperature, which is within the range of 20°o 27°C. The engine oil temperatures are similar, while the corresponding distributions do not change for each truck at the various distances. The intake manifold temperature and engine coolant temperature distributions show different trends related to the platooning distance. These temperatures are consistent for the three trucks when the distance is larger than 20 m. When the distance is less than 20 m, the middle and trailing trucks will have higher distributions for both the intake manifold and engine coolant temperatures compared to the leading truck's. These higher temperature distributions are more distinct when the distance is shortest. At the smallest separation distance of 4 m, the middle and trailing trucks' intake manifold temperatures are 12°C higher than the leading truck's, and the related engine coolant temperatures are 10°C higher than that of the leading truck.

Another observation on these four temperature distributions is that the intake manifold and engine coolant temperatures are fairly condensed when the separation distance is larger than 12 m. These two distributions become quite scattered when the distance is reduced to the shorter distances (9 m, 6 m, and 4 m cases). Such a phenomenon may be caused by the fact that the engines in the trucks in a close platoon may operate in unstable conditions due to the variable turbulent airflow to the cooling package. It is worth noting that the engine oil temperatures for all the three trucks share a similar distribution at various separation distances. Usually, the bulk of the engine oil temperature distribution is distributed around 110°C with a tail below 105°C. It is assumed that the oil temperature is tightly controlled in the engine within an appropriate window, and thus its distribution can be kept almost fixed no matter what thermal conditions the engine faces.

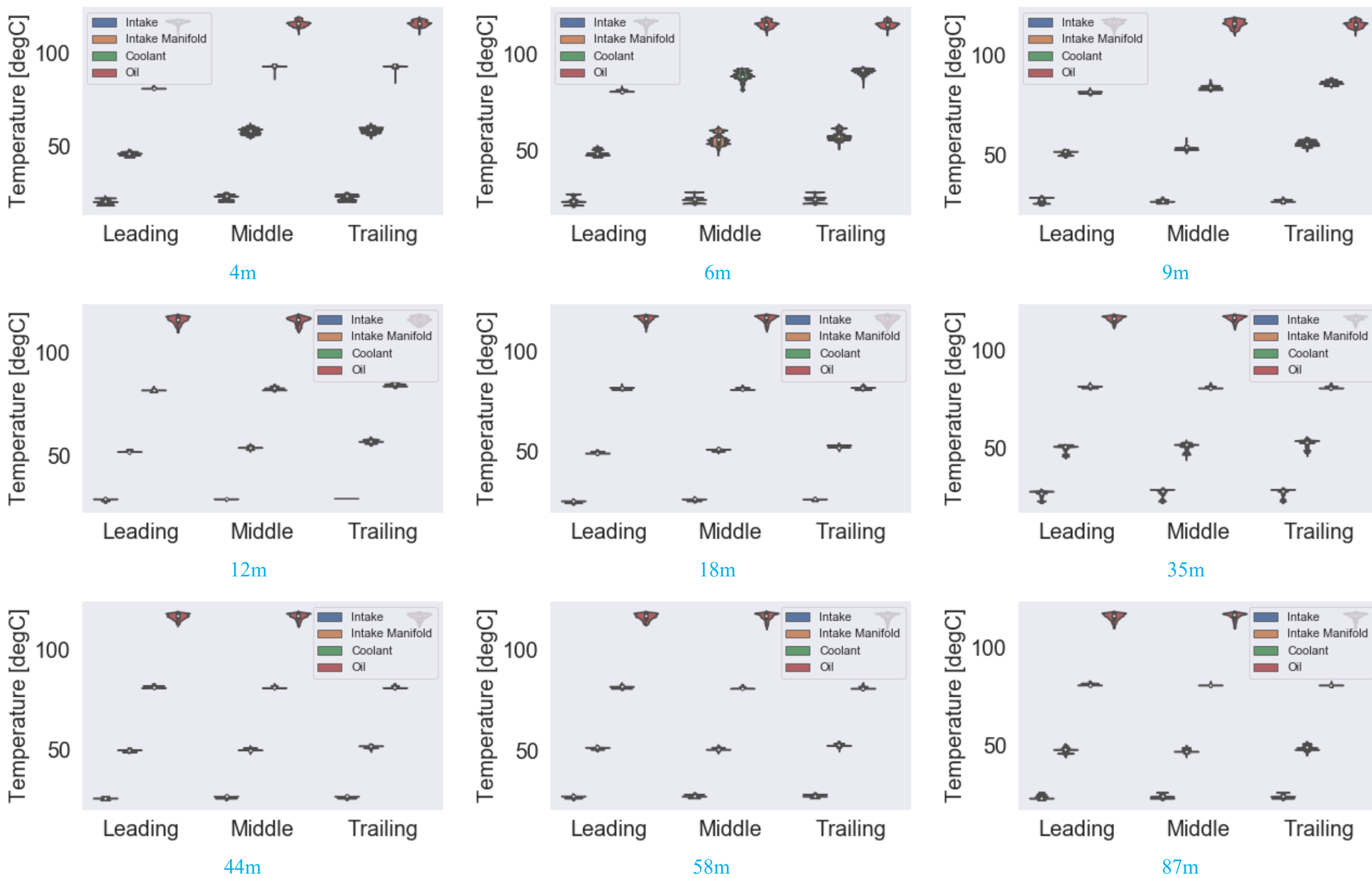

Figure 18. Violin plots of inside engine temperature distributions at various separation distances in the three-truck platooning test

Summary/Conclusions

The 2017 track test collaboration among NREL, Lawrence Berkeley National Laboratory, National Resource Council Canada, Transport Canada, and others was conducted to gain a deeper understanding of the fuel savings potentials of truck platooning impacted by real-world conditions. The tracking tests include a three-truck platooning travelling at 105 km/h (65 mph) and loaded to a gross weight of 29,500 kg (65,000 lb), at different distance gaps ranging from 3.0 s or 87 m to 0.14 s or 4 m. The results have shown significant fuel-savings promise for truck platooning strategies, but also raised unexpected questions about the reduced saving potential at close following distances. The goal of this work was not to recommend an optimal platooning gap distance from a thermal perspective, but rather to make engine and truck makers aware of the thermal impacts of platooning. This information can be used to enable thermal system design changes to mitigate those impacts and enable the close following platoon fuel savings.

This paper documented the analyzed results of the thermal system of the trucks during a specific three-truck platooning test and explored the thermal management system impacts. It is postulated that the lower speed air wake of the leading vehicle leads to lower stagnation pressure over the front surfaces of the trailing vehicles, impacting engine cooling performance at platooning distances less than 20 meters. By analyzing several temperature distributions inside and outside the engine during the tests, specific conclusions from the work are as follows:

- The middle and trailing trucks have slightly elevated air temperatures at the boom location over the lead truck's temperature at close following distances.
- A temperature rise exists between the air temperatures measured by the boom location thermocouple and the under-hood thermocouple grid. Such temperature rises on the middle and trailing trucks are significantly impacted at distances less than 18 m, but are quite similar to the lead truck temperature beyond 35-m separation distance. Specifically, when the platoon distance is 4 m, the average temperature rises on middle and trailing trucks are 10°C higher than the rise in the leading truck.
- The temperature rises from the intake air sensor to the intake manifold in the engines of three trucks have the similar trend as the boom location and under-hood temperatures. The leading truck' temperature rise is almost a constant, within the range of 22.5 to 25°C for various distances in the test. The average temperature rises in both the middle and trailing trucks are comparable to temperatures in the leading truck when the distance is longer than 20 m, but increase significantly when the platoon distance is reduced. The average temperature rise of the following trucks can reach 35°C in the 4-m distance case, which is 12°C higher than the temperature rise in the leading truck.
- For separation distances less than 20 m, the average coolant temperatures in the middle and trailing trucks are raised from 81°C to 92°C, while the average coolant temperature in the leading truck is around 82°C.
- In addition to the average temperatures, the distributions of the intake manifold and engine coolant temperatures in the middle and trailing trucks also have more scatter compared to the leading truck's when at close following distance. This

observation reflects that the engines in the middle and trailing trucks may operate in relatively more unstable ram air flow conditions compared to the engine in the leading truck experiencing free stream ram airflow.

The analyzed results show that the engines in middle and trailing trucks in close-distance platooning experience warmer operating conditions. In the future, more in-depth investigation is planned for this issue, which will include development of a computational fluid dynamics model for simulating turbulent flows within a truck platoon.

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Definitions/Abbreviations

ACC	Adaptive Cruise Control
CACC	Cooperative ACC
CAN	Controller Area Network
NREL	National Renewable Energy Laboratory